A Proposal

GPS Reflection Experiment for Ultra Long Duration Balloon Platform

Submitted by:

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1. Introduction:

This proposal consists of installation, flight, and data analysis of a GPS receiver system capable of acquiring signals reflected from the surface of the ocean, land, and ice and flown on an Ultra Long Duration Balloon (ULDB.) In the following discussion, background on this new GPS application and technique will be presented, a description of the experiments an ULDB will make possible, and related activities currently being conducted.

2. Background:

In 1994, French researchers reported acquisition of ocean-reflected GPS signals during routine tests of an experimental aircraft. The flight-testing was done out over the French coast, with the reflected signal only significant over the water. The French researchers demonstrated that it was indeed the water-reflected signal; they identified fixes for the problem, implemented the fixes and dropped the work. U.S. government researchers at NASA's Langley Research Center in Hampton, Virginia noted the potential use of the surface reflection as a new remote sensing tool and began to advance the French work. The particularly high reflectance of water and metal objects at L-Band helps to compensate for the small power in the GPS signal. Many already developed applications of L-Band illumination can be transferred to a GPS version with reasonable expectation of success. Examples are imaging, scatterometry, crude altimetry, wetlands mapping, and possibly ionosphere corrections for single frequency altimeters such as GEOSAT Follow-On. Since the GPS signal typically is forward scattered, the scatterometer applications can be complementary to conventional backscattering. In addition, the great distance to the GPS satellites means that fundamental footprints on the surface can be as small as a few Fresnel zones or about 0.01-km (aircraft altitudes)-1 km (spacecraft altitudes) with only a hockey-puck-size antenna. All of the applications can be accomplished with instrumentation of almost zero platform impact and no radiated signal. Thus, the GPS surface reflection technique can easily be implemented on spacecraft, light aircraft, RPV's or balloons and used for simple, broad-area coverage.

Modeling, experiment and analysis have been underway since 1997 with considerable progress made so far. The Langley group modified a GEC Plessey dual front end GPS receiver for the scatterometry application, and have flown the receiver on a large number of aircraft flights at altitudes from 200 meters to over 8 kilometers. In August 1998, a balloon flight to 25 kilometers over the Atlantic was completed and a flight on an ESA balloon from Sicily to Spain was completed in July 1999. A NASA-Langley system was recently installed on a NOAA Hurricane Hunter and recorded data from Hurricane Michael off the East Coast.

3. Wind speed and direction:

The focus of GPS surface reflection research is on sea surface wind speed measurements. Recently, a matched filter approach to wind speed retrieval has been tested with very good results and equivalent performance to non-linear estimation methods. The advantage to the matched filter approach is the speed with which the retrievals can be effected. Simple tests have shown the ability to retrieve wind speeds considerably faster than the data is acquired.

3.1. Wind Speed:

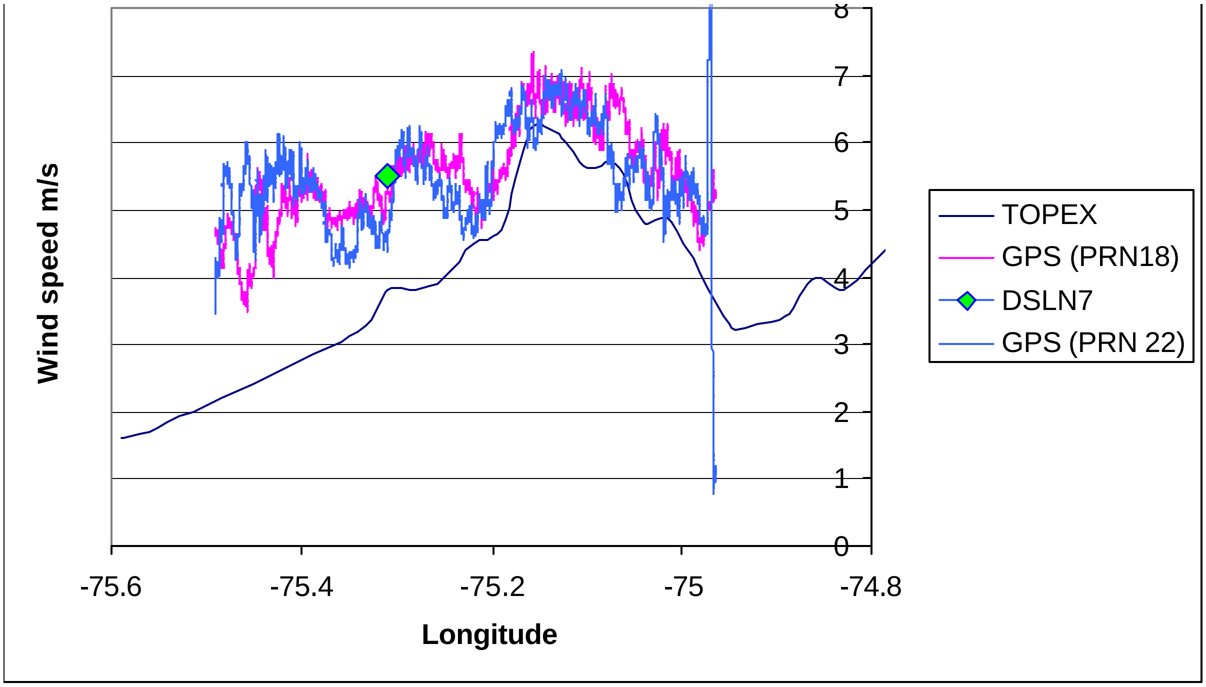
Application of GPS signals reflected from ocean surface has focused upon retrieving wind speed and direction based on analysis of return signal shape [Katzberg and Garrison, 1998; Garrison et al., 1997; 1998; 1999; Lin et al. 1999; Zavorotny and Voronovich, 1998; 1999; Komjathy et al., 1998; 1999]. Wind speed accuracies in the range of 1-2 meters per second when compared to TOPEX or buoys has been demonstrated. Wind direction retrievals have also been demonstrated, within the typical accuracies (and ambiguity) of scatterometers. L-band reflected GPS signal measurements obtained at typical balloon or UAV altitudes can be expected to yield a wind field spatial resolution of the order of one kilometer.

Models have been developed which permit wind speed retrievals up to 24 meters per second. However, no models currently exist for wind speeds in the tropical storm regime. One of the research objectives of this proposal is to provide extension of the data into the multi-tens of meters per second and to evaluate the capability of the GPS technique to provide accurate wind speed information above 24 meters per second.

It is well known from signal theory that the maximum response from a linear filter occurs if the signal is fed through a filter whose impulse response is a time-reversed copy of the input waveform. In the ideal case, the signal is contaminated by uncorrelated noise. For the GPS receiver case, the transmitted signal power-spectral-density at the earth's surface is below the additive thermal noise from the receiver front-end. With a stable, GPS transmitted power; the conditions exist for matched filter techniques. However, when the transmitted signal encounters the rough water surface, an additional noise is developed from the random phase shifts for each individual wave facet or surface area. The signal takes on the characteristics of "fading noise" with the "noise" coming from the signal itself as well as from thermal sources.

It can be shown that producing the peak signal-to-r.m.s-noise ratio comes from convolution of a time-reversed replica of the input signal. The effect of time reversal converts the convolution to a cross-correlation. In the case here this convolution is equivalent is sliding copies of all the possible waveforms against the experimental signal samples for any given altitude and elevation angle for the satellite producing the reflected signal.

Shown in the figure above is a comparison of data from November 19, 1999 under-flight of TOPEX out from Cape Hatteras, NC. Data from Diamond Shoals Light at the time of the TOPEX overpass is shown as the triangular marker near 75.3W degrees. The more negative longitudes near the buoy marker represent the approach of TOPEX to land and consequently, unreliable results.

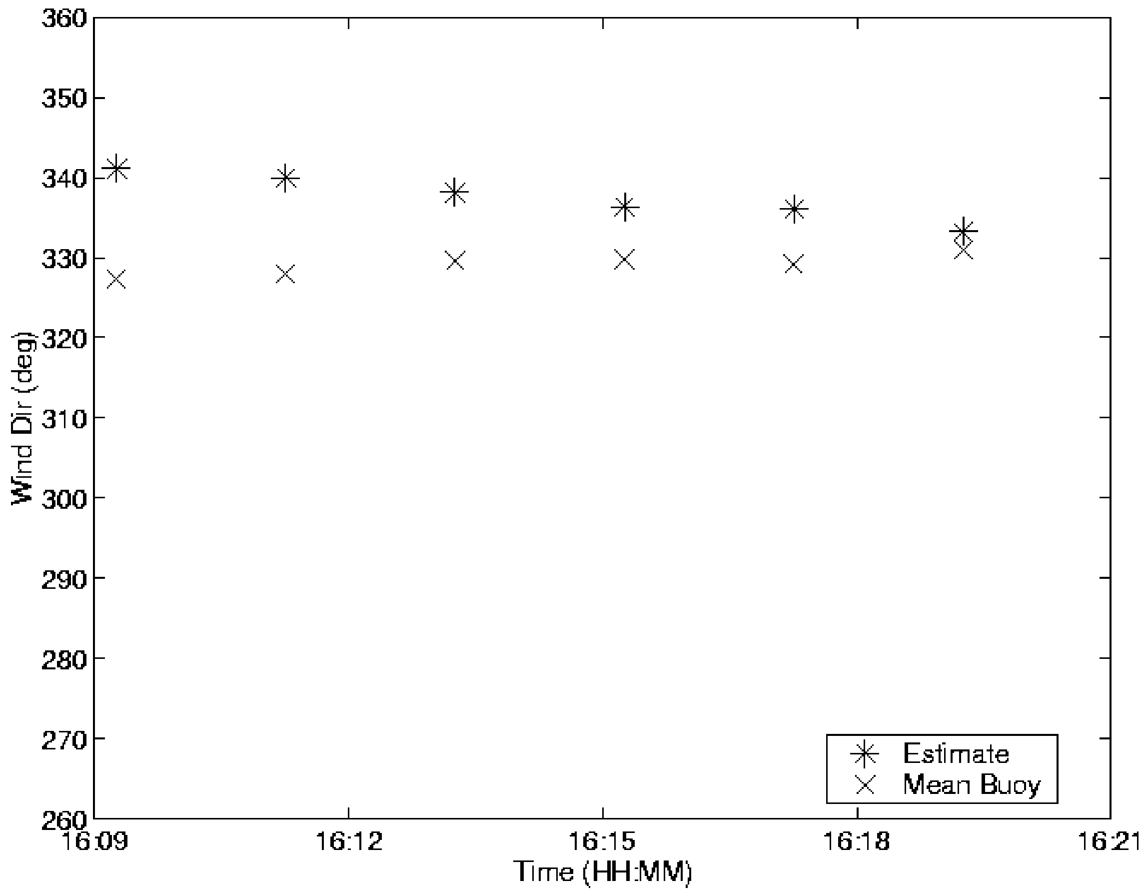


Two satellites were utilized in this retrieval, with the beginning of data take out near 74.8W. The large transient is the initial acquisition of PRN (22). Note that the transient disappears rapidly.

3.2. Wind Direction:

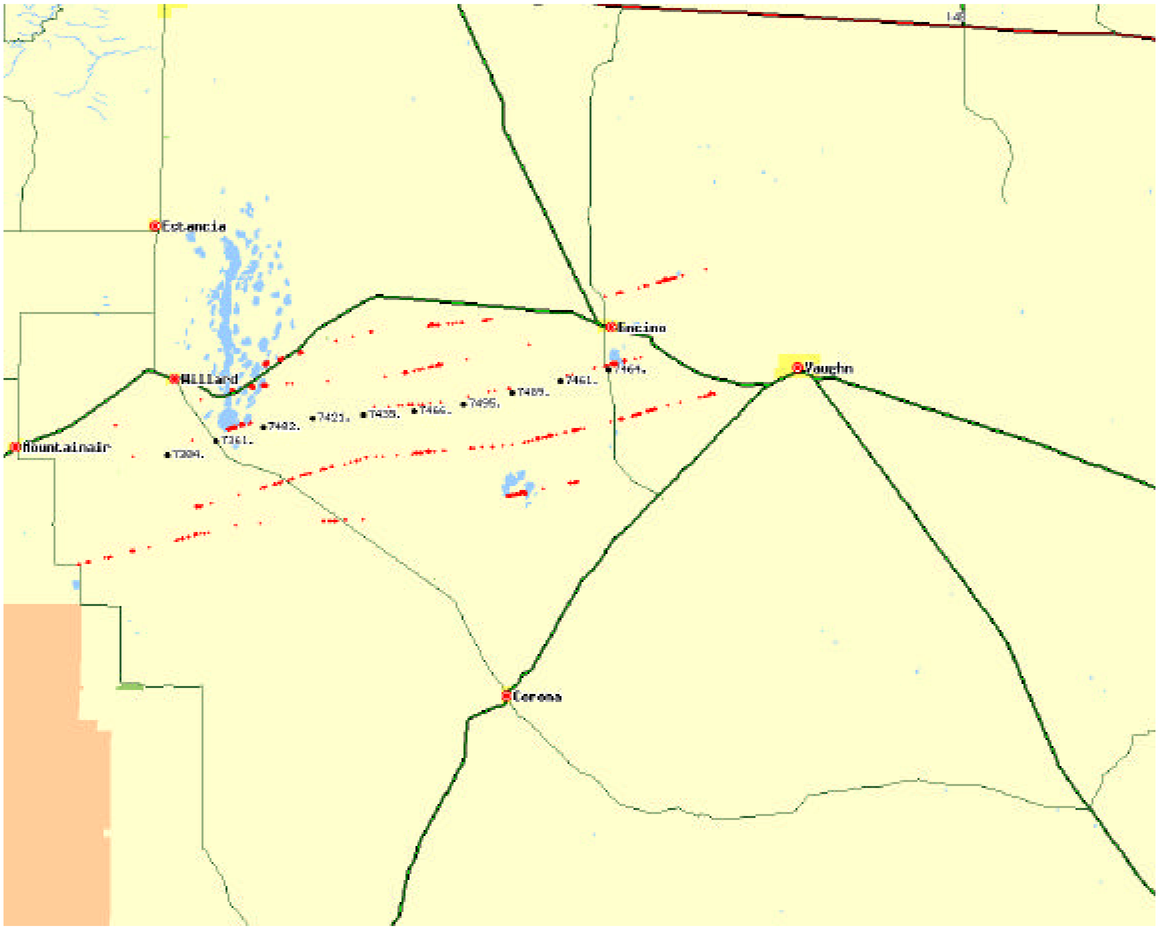
Wind direction has generally taken a back seat to wind speed until relatively recently. It has been assumed that deriving wind direction would be more difficult than wind speed. Consequently, the simpler problem of wind speed was addressed first. Lately, there has been evidence that wind direction can be extracted relatively easily and with somewhat surprising accuracy.

Generally, the scattering function for the GPS signal is dependent on wind speed, which affects the "width" in scattering angle and wind direction, which affects the anisotropy of the scattering function. The detected signal is such that it effectively represents an integration over scattering angles that tends to "wash out" the anisotropy due to wind direction. A wind direction investigation is being done by one of the graduate students involved in the GPS research at the University of Colorado, Michael Armatys. This work has been based on performing a principal components decomposition of the detected GPS signal without attempting to determine the wind speed, *per se*.



4. Soil moisture

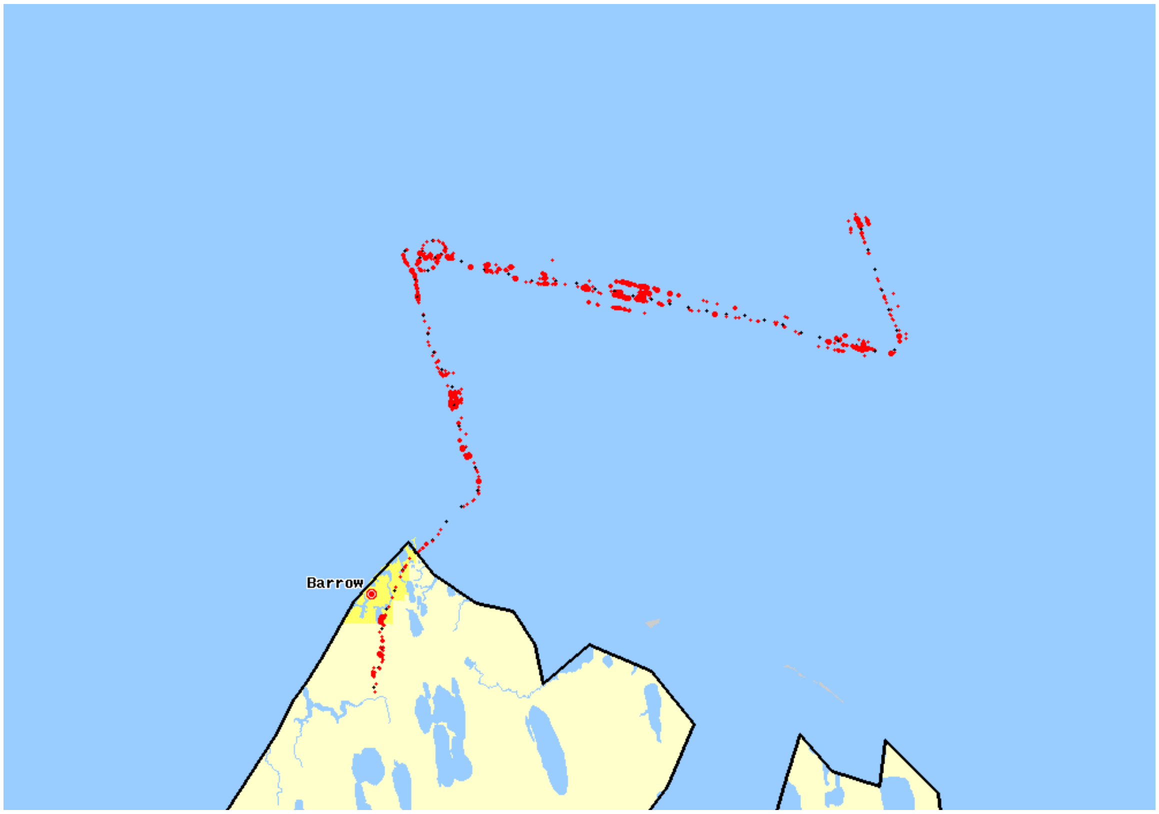
Use of the reflected GPS signal for covert imaging and soil-water-content detection is also under investigation. The GPS RF field easily penetrates desert soil down to several feet while wet soil reflects strongly near the surface. Coupled with the readily available position information, accurate location of the signal sources is simply accomplished. A deployment was done in 1998 to Davis-Mothen Air Force Base in Tucson AZ. The objective of the flight was to study the reflection of GPS signals by aircraft bodies and determine the existence of subsurface water in desert areas. During the flight back, data was taken over New Mexico south of Albuquerque out to near Lake Sumner. Aircraft altitude was around 20,000 feet. The figure shows the reflection of each of six GPS satellite signals from their image locations on the desert surface. The red traces are areas where a strong signal is returned as the image of the satellite tracks along the ground. Lakes are easily identified as are areas in the desert, which should be dry (and were to the aircraft flight crew.) In addition, it is apparent that the GPS appears to be particularly attracted to highways. It is clear from the data that the GPS can locate areas with strong signals arising from the desert that would be unobtainable by other means.



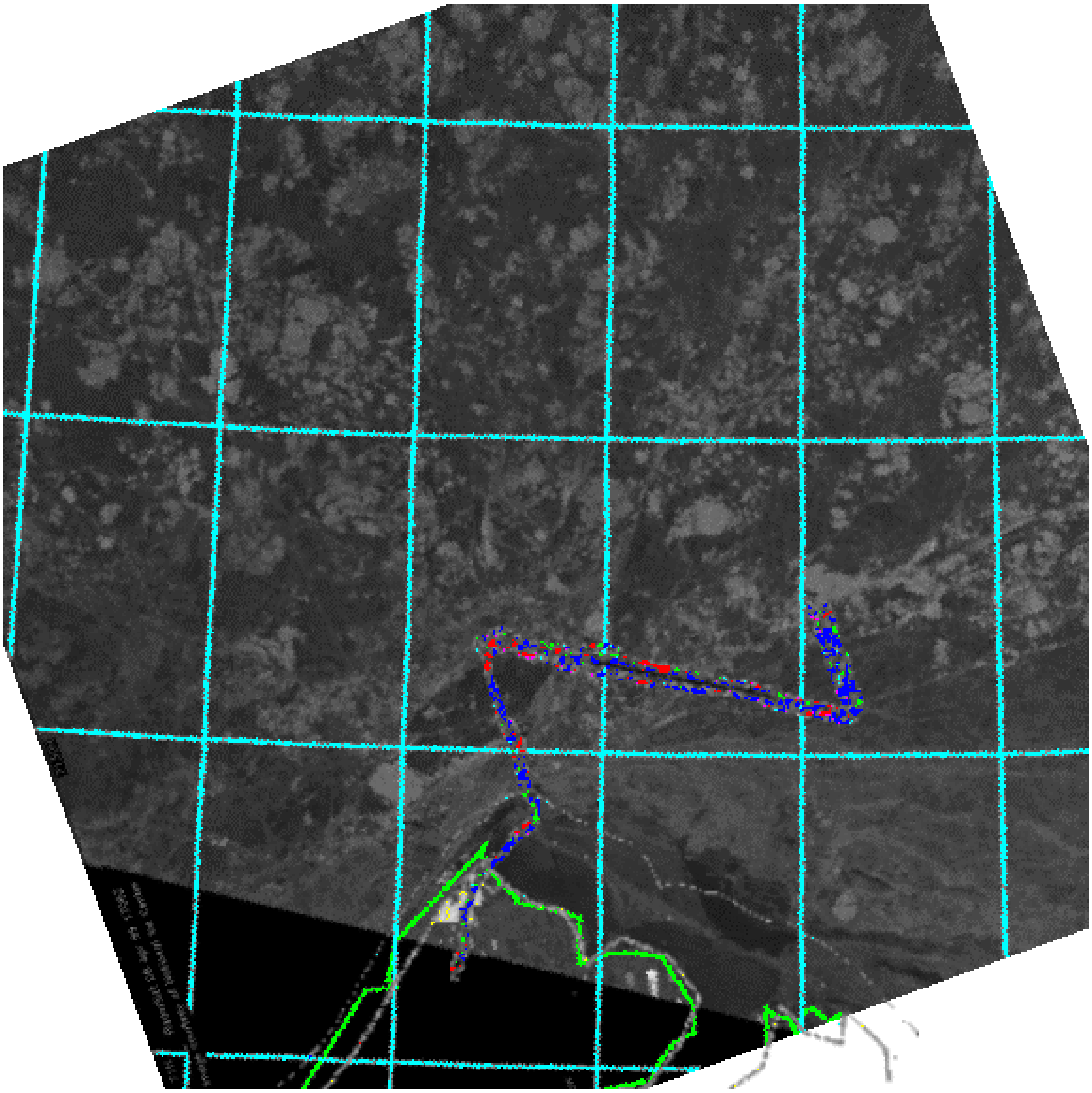
5. Initial experiments involving ice

It is also known that ice has a low index of refraction at the L-Band frequency of GPS. Thus, the GPS signal should penetrate ice (ignoring scattering) down to the ice-water interface, if one exists. It should be possible to learn something of the spatial characteristics of ice fields utilizing the reflected GPS signal. Early attempts to examine this possibility have taken place

The following is a map of the GPS reflected signal taken during latter March of 1999. A modified GPS receiver on loan from NASA-Langley Research Center was flown in a light aircraft off Barrow AK during a research activity from the University of Colorado. The data was converted into a map format similar to the preceding figures. The aircraft flew out over the ice and then retraced its flight path. The black dots are flight path sample points, while the red dots are again the reflected signal; with large dots the strongest signal. It is evident that the GPS signals uncovered structuring of the ice-water system.



In addition, a RADARSAT image taken near the same time was used for a comparison overlay of the two data sets. It has been shown that the RADARSAT backscatter is sometimes strongly anti-correlated with the GPS signal while other areas on the ice show strong positive correlation.



6. Science Team:

The GPS surface reflection experiment will have an informal science team consisting of members from this research community who would like to share in the data available from the extensive data sets derived from global circumnavigation.

7. Instrumentation:

Most of the GPS reflection experiments to date have been conducted with the Delay Mapping Receiver (DMR) designed by Katzberg and Garrison [1997]. The DMR has two antenna inputs to allow standard tracking of direct signals. The innovation of this design is that unlike a conventional GPS receiver, the DMR does not attempt to perform closed-loop tracking of the reflected signal; but rather, it uses some of the receiver channels to make measurements of the correlation between the reflected signal and shifted versions of the local signal replica. Receivers to measure GPS returns are relatively small and inexpensive. The current system developed at NASA Langley Research Center consists of two small GPS antennas, a modified GPS receiver, processor, data recorder, and cables. This package weighs less than 5 kg, and operates on less than 15 watts, which can be supplied by batteries. S. Katzberg at Langley Research Center will provide a smaller system for this project.

A receiver version has already been built for a balloon application and tested thermally and at equivalent atmospheric pressure. This receiver is to be flown on a NOAA balloon experiment to be launched from Tillamook, OR. The figure below shows a collage of photographs taken during the integration of the DMR instrument on the NOAA balloon. The upper right corner, top center, and lower left corner show the progress of the instrument integration into the torus shaped gondola, the right center shows the instrument as it appears during final closeout before integrated test. The lower right shows the gondola being prepared for the integrated RF test, and the upper right shows the gondola as it was suspended during the RF test.

NASA-Langley will provide GPS receivers fully compatible with the ULDB operational environment. These receivers will operate within a 15 watt power envelope, weigh less than 2 kilograms, and will be fully autonomous in operation with their own data storage system. Langley will provide the necessary integration support to successfully install, check out and demonstrate operation of the GPS receivers.

Current balloon GPS reflections receiver

Power: 15 watts at 12volts dc
Mass: approximately 2 kg
Size: 23 cm x 15 cm x 12.5 cm
(9"x6"x5)

•Generates position solution and Reflected signal. Output format Ascii files. Self-contained CPU Can function as stand-alone PC.

•Utilizes two flight certified antennas

8. Payload Operations:

Occasional downlinks of data sets would be desirable, but not required in view of the autonomous operation of the receiver. Data would be removed post flight and operation of the receiver would be controlled via any number of power-on, power-off circuits available for this purpose.

9. Integration:

Integration will be supported by NASA-Langley if required. Hardware simplicity will be emphasized in the delivered GPS system so that platform integration will be uncomplicated.